TRANSPORTATION OF DEBRIS BY ICEBERGS

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Introduction.—On the east valley side of the southern end of the Cayuga Lake Valley, just to the north of Ithaca, New York, occur considerable areas of lake-clay deposits laid down when the waters of the lake were ponded to higher levels by the ice barrier of the retreating front of the last advance of the continental ice sheet. These lake-clay deposits are especially well developed in the zones marginal to the outer fronts of the higher-level deltas of streams tributary to the Cayuga Valley, and undoubtedly represent, in such cases, the extension of the bottom-set beds of the delta accumulations. The particular occurrence to which reference is made in this article is found at a level of 840 feet to the south and west of the top of a notable delta deposit of Fall Creek, having an average elevation of 930 feet (the block diagram, Fig. 1, illustrates the geography of the occurrence). Thus the clay may be assumed to have been laid down in water having a depth of 90 feet and removed from the nearest point of the steep front of the delta deposit by a little less than one-fourth mile. At the time when the delta and clay deposits were made the ice barrier must still have existed within the confines of the Cayuga Lake Valley, for the level of the delta top indicates that its building must have been coincident with the outflow of the lake waters across the north-south divide between Cayuga and Seneca Lake valleys, and the overflow of their combined waters was at a present elevation of 900 feet from the south end of the Seneca Lake Valley into the Chemung River and thus into the Susquehanna. On the other hand, it is unlikely that the ice barrier was immediately adjacent to the delta and lake-clay deposits, for the nearest point of the north-south divide with a low enough elevation to permit of a flow of water from the one lake valley to the other is found approximately 15 miles to the north

of their occurrence. To the south the divide is at every point much higher than 900 feet. Unless, therefore, the ice front is conceived as a long projecting point occupying the center of the lake valley and margined by lake waters on both sides for a considerable distance, the ice barrier should be placed comparatively remote from the site of the clay deposit. This concept is also in accord with observation of tidal and marginal-lake ice fronts in Alaska—there is an almost straight line truncation of the ice where it is fronted

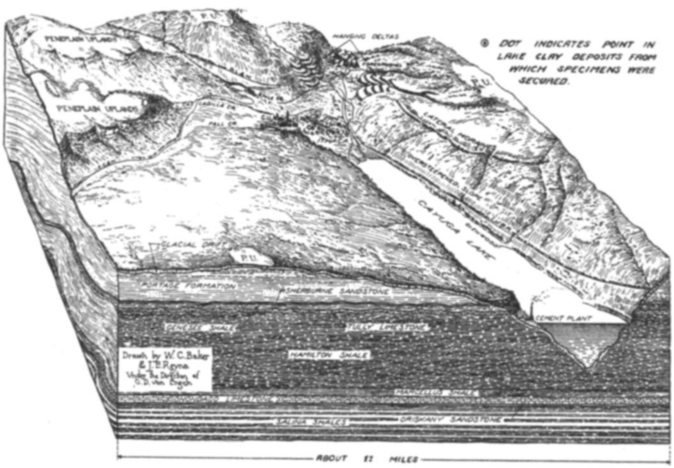

FIG. 1.—Block diagram of the region around the southern end of Cayuga Lake, New York.

by deep water. Again, the lake clay at the occurrence described has a thickness of at least 10 feet, and perhaps double that, with perfect, undisturbed stratification indicating a relatively long-continued period of deposition unaffected by minor oscillations of the ice front.

Purpose of paper.—It is the purpose of this paper to recount the recovery of rock material from a limited area and depth of this lake clay, to indicate the amount and character of this material, to account for its presence, and to make certain deductions from these facts with regard to the character and effectiveness of the erosive activities of glacial ice.

Recovery and nature of material.—In the course of gardening operations a trench approximately 25 feet long, 4 feet wide, and 3 feet deep was made in the lake clay. The clay deposit continued right up to the surface and was undisturbed and unmodified except for the top 12 or 16 inches that had been rendered more friable and amorphous in structure by plant growth and tillage. Below that the clay was exceedingly compact, fine grained, and slightly jointed with one-half- to one-inch spacing. From this clay, below the soil

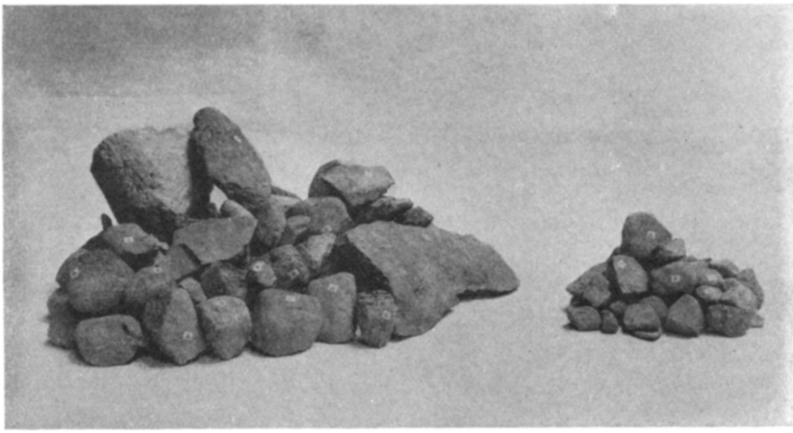

FIG. 2.—Iceberg-dropped bowlders recovered from lake-clay deposit. Smaller pile apparently from single berg. Those marked *A* are striated or soled. Left to right diameter of bowlder at top of small pile is three inches.

layer, were dug the bowlders illustrated in Fig. 2. For the most part these were found in clusters of from three to five or more specimens occurring near each other. The bowlders in the smaller pile in Fig. 2 were all clustered within some 3 cubic feet of the clay at about the same depth. The total weight of all the bowlders is 74.5 pounds, of those in the smaller pile 8.5 pounds. In addition there were no doubt other rather large-sized bowlders that were overlooked, as no effort was made to go over the material with extreme care; and many observed smaller pebbles were not preserved. In any event the actual mass of the material present within the space excavated has no special significance; the figures are quoted merely to give some idea of the quantity of such bowlder

inclusions within the particular section of the clay that was examined. Possibly adjacent areas might have much greater masses, but the probability (as indicated by inspection of other near-by excavations) is that the average number would be lower, though occasional very large bowlders might make the mass as great, or greater, per average cubic foot of clay. It should be noted that away from the spots where the clustered bowlders occurred the clay was almost absolutely free from sand or grit.

Two distinctive charactersitics are immediately apparent on inspection of the material: (1) Many of the specimens (26 per cent of their number) show signs of glacial grinding, have striations, are "soled," or rudely faceted. In Fig. 2 a number of these are indicated by the letter *A*. (2) Much of the material (55 per cent by number, 67 per cent by weight) is from quite distant outcrops, that is, of rock material not available at the surface for a distance of 50 miles or more to the north even if the bottom of the lake is taken into consideration. Twenty-two of the 125 bowlders come from so distant a source as the Adirondacks or perhaps from Canada. There are 3 granites, 1 syenite, 12 gneissic, and 6 schistose specimens irrespective of size. Very prominent in the foreign material are Medina sandstones and Potsdam sandstones and conglomerates; of these three varieties there are 46 specimens. With one exception the large fragments, in general, are of the more resistant rock kinds from distant sources. The exception is a notably large piece of local sandstone derivable from bedrock outcrops extending from the area of the clay deposit to 10 or more miles to the north. This large local specimen is very conspicuously ground off on one side.

Source of the bowlders.—The only feasible explanation of the occurrence of these large rock fragments interbedded with the fine clay is that they are iceberg droppings. Icebergs, calved from the relatively distant glacier front, floated over the areas on which the clay was depositing and, on sufficient melting, dropped their rock load into the fine clay sediment, later deposits of which buried them completely. The bergs do not seem to have been grounded, for there is no apparent disturbance of the clay layering, though the clay material is so fine that in its oozy, under-water condition it

may have been too fluid to register so temporary a disturbance as the rocking and melting of a stranded berg.

Almost similar conditions of deposit of débris by icebergs have been observed on a tidal flat adjacent to the end of the Columbia Glacier, Alaska. There, at low tide, were exposed wide areas of fine-grained clay deposits. All over the surface of these clay deposits were scattered "nests" of glacial bowlders deposited by icebergs (calved from the adjacent Columbia Glacier) that had floated over the area at high tide (Fig. 3). The streaks on the mud

FIG. 3.—Bowlders dropped by icebergs on tidal mud flat adjacent to front of Columbia Glacier, Alaska. Streaks are due to the dragging of the bottoms of bergs floating in and out with the flow and ebb of the tide.

are occasioned by the dragging of partly floating bergs with the ebb of the tide. Similar "nests" of iceberg-deposited bowlders were a common feature on the sand beaches of the west side of Yakutat Bay, Alaska (Fig. 4). Here the pits in which the bowlders are nested are conspicuous because successive tides rocked the stranded bergs (Fig. 5) back and forth sufficiently to make quite an excavation before the ice melted completely.

Significance of observations.—From the foregoing observations of deposits adjacent to Pleistocene ice fronts and near living glaciers it is apparent that icebergs can and do carry notable quantities of

rocky débris and may deposit this at considerable distances from the calving end of the glacier. The fact that so large a percentage of the bowlders found in the clay deposit showed evidence of wear indicates that the material was largely derived from the bottom ice of the glacier. In fact, in collecting specimens of glacially striated pebbles, it is the common practice in this locality to resort to a deposit of glacial-lake clay for the material, as a large proportion of the bowlders found in such deposits exhibited these markings remarkably well preserved. Assuming that each of the bowlder

FIG. 4.—"Nests" due to rocking of stranded icebergs. Pebbles and bowlders on the surface of the sand and in the pits were included in the ice and deposited on its partial or complete melting. West side of Yakutat Bay, Alaska.

"pockets" in the clay is the result of the melting down of a single berg (and this seems very clearly to have been true of the material included in the smaller pile of Fig. 2 at least), it follows that the bottom ice must have been quite thickly shod with rock fragments. In other words, the material in transport at the bottom of the ice in any one cross-section must have been of considerable mass, and this material could have been acquired only by actual ice erosion of the bedrock over which it passed. Such being the case, the striking absence of local rock material in these iceberg deposits acquires a particular significance. It would appear that the local

rock material, being of comparatively slight resistance to grinding (mostly shales and thin bedded sandstones, commonly argillaceous), is reduced to rock flour almost immediately, while the resistant quartzitic and igneous material from distant sources survives. An alternative interpretation is that the local material of little resistant nature is not much subject to plucking, is eroded only by grinding, hence yields few sizable fragments. The same conclusion is suggested by the fact that the large-sized surface and near-surface erratics of local origin in the glacial deposits of the area about

FIG. 5.—Stranded icebergs, showing some with included débris. West side of Yakutat Bay, Alaska.

Ithaca, New York, are in very high percentage fragments of the Tully limestone, which outcrops in relatively massive layers, 2 to 10 feet thick, about 4 miles to the north of Ithaca and at other points more remote. It is also of interest to note that these large Tully erratics are in almost every case very conspicuously smoothed by ice wear and have usually the appearance of having lost a considerable part of their mass by such grinding, though it is of course commonly rather difficult to estimate how large the plucked block was originally. That the single large, local sandstone fragment found in the clay deposit was also very notably ground off is evi-

dence of the same kind. Specifically the fact that both the Tully limestone erratics and the local sandstone fragment in the iceberg deposit show conspicuous wear indicates that in the short distance such fragments traveled, and presumably under the thin, waning front of the glacier, there was nevertheless accomplished a very notable amount of erosion of these fragments, and it may be inferred that the bedrock surface over which the fragments were dragged was subjected to a like amount of reduction. This suggests that even the relatively thin and inactive frontal lobes of waning glaciers are quite effective erosive agents.

Summary.—Iceberg deposits of bowlders, found in fine-grained lake clay, occur in pockets, as if derived from single bergs. If that is the case the material brought by each berg is of considerable mass. The bowlders are in very high percentage of foreign, resistant rocks, and a very large proportion of the specimens shows signs of mechanical wear of glacial nature. Hence it is concluded that the iceberg deposits examined were from the bottom ice of the glacier. Locally derived material found in the deposits shows similar wear. Since these iceberg deposits must have been the very last deposits made by the last retreat of the ice, it is argued that the notable grinding of the local material indicates that even the thinned lobes of a waning glacier had considerable erosive effectiveness.